ANSWERS: Properties of substances

QUESTION: Justify each of the properties of the following substances

<table>
<tr><th>electrical conductivity</th><th>melting & boiling points</th><th>solubility</th><th>malleability</th></tr>
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<td>Magnesium oxide is made up of positive magnesium ions and negative oxide ions held together by electrostatic attractions in a 3–D lattice.
Magnesium oxide does not conduct electricity as a solid as these ions are not free to move. When molten the ions are free to move and carry the charge so magnesium oxide conducts electricity.</td>
<td>H_2O – weak force of attraction circled (force between adjacent molecules).
The forces of attraction between neighbouring water molecules in ice are weak. Only a small amount of energy is required to separate the water molecules from each other, hence ice has a low melting point.</td>
<td>Magnesium atoms are held together in a 3–D lattice by metallic bonding in which valence electrons are attracted to the nuclei of neighbouring atoms.
Magnesium does not dissolve in water because the metallic bonds are too strong to be broken by the attraction to the water molecules.</td>
<td>Magnesium atoms are held together in a 3–D lattice by metallic bonding in which valence electrons are attracted to the nuclei of neighbouring atoms.
Magnesium is malleable because the force of attraction between the valence electrons and the nuclei of the magnesium atoms is non-directional. This means that the layers can slide over each other without breaking the metallic bond / disrupting the lattice structure.</td>
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<td>Diamond does not conduct electricity and is hard. Diamond consists of C atoms each covalently bonded to four other C atoms, forming a 3-D tetrahedral arrangement. In diamond, all of the valence electrons in each carbon atom are involved in bonding to other carbons. There are no mobile electrons to carry charge. Therefore, diamond is unable to conduct.</td>
<td colspan="2">Bonding in SiO_2 is covalent bonds between atoms
SiO_2 is made up of Si and O atoms. Each atom is covalently bonding to four others in a tetrahedral arrangement forming a covalent network solid. The covalent bonds are very strong and:
• (for melting point) require a large amount of energy to overcome them, meaning SiO_2 has a high melting point
• (for solubility) are too strong to be broken by the attraction to the water molecules.</td>
<td>Zinc consists of Zn atoms held together in a 3–D lattice by metallic bonding, in which valence electrons are attracted to the nuclei of neighbouring atoms. The attraction of the zinc atoms for the valence electrons is not in any particular direction, so therefore zinc atoms can move past one another, and so zinc is malleable.</td>
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<td>Graphite does conduct electricity. Graphite consists of C atoms each covalently bonded to three other C atoms in a 2-D or layered arrangement with weak intermolecular forces of attraction between the layers or sheets. However, in graphite each carbon atom is bonded to three others in the layers and has one valence electron, which is free to move. These delocalised electrons result in the ability of graphite to conduct electricity.
Graphene
Each carbon atom is bonded to only three other</td>
<td colspan="2">Bonding in Br_2 is weak intermolecular forces of attraction between molecules
Br_2 is a molecular substance made up of molecules. There are weak intermolecular forces holding the molecules together and:
• (for melting point) require only a small amount of energy to overcome them meaning Br_2 has a low melting point
• (for solubility) the attraction of the water molecules is sufficient to separate the bromine molecules, meaning Br_2 is soluble in water.</td>
<td>Zinc chloride consists of a regular array of zinc and chloride ions held together by ionic bonds in a lattice. The bonds within $ZnCl_2$ are directional so $ZnCl_2$ is not malleable</td>
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</table>

carbon atoms. Therefore each carbon atom has free / delocalised /valence electron(s), to conduct electricity.		

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<td>Copper is composed of Cu atoms /cations (NOT protons or nuclei) held together in a 3–D lattice by metallic bonding, in which valence electrons are attracted to the nuclei of neighbouring atoms. The delocalised electrons / valence electrons are free to move through the lattice; therefore they are able to conduct electricity.</td>
<td colspan="2">NaCl – ionic bond circled (force between positive and negative ions).
Sodium and chloride ions are held together by strong ionic bonds. A large amount of energy is required to overcome these forces. Hence NaCl has a high melting point. When sodium chloride dissolves in water the ionic lattice breaks up. Water molecules are polar. The positive hydrogen ends of the water molecules are attracted to the negative ions (Cl–) in the lattice, and the negative oxygen ends of the water molecules are attracted to the positive ions (Na+). The attraction of the polar water molecules for the ions is sufficient to overcome the attractive forces between the Na+ and Cl– ions, allowing them to be removed from the lattice. Hence the sodium chloride solid dissolves, forming separate Na+ and Cl– (ions) in aqueous solution.</td>
<td>Silver atoms are held together in a 3-D lattice by metallic bonding, in which valence electrons are attracted to the nuclei of neighbouring atoms. As this is a non-directional force, layers of atoms can slide over each other without breaking the metallic bond and disrupting the structure and breaking the metal.</td>
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<td>Sulfur is made up of sulfur molecules in which sulfur atoms are covalently bonded to each other. It does not contain mobile charged particles (no free electrons or mobile ions). Therefore sulfur cannot conduct in the solid or liquid state.</td>
<td colspan="2">$MgCl_2$ is made up of ions. $MgCl_2$ has a high melting point. It is an ionic solid. It consists of a 3–D lattice of positive Mg^{2+} ions and Cl^- ions and the ions are held together by strong ionic bonds. As a lot of energy is required to overcome these strong bonds to separate the ions, the solid has a high melting point. $MgCl_2$ is soluble in water, Water molecules are polar. When $MgCl_2$ is placed in water, the oxygen ends of the water molecules are attracted to the positive Mg^{2+} ions, and the hydrogen ends of the water molecules are attracted to the negative Cl^- ions. The water molecules then pull ions from/destroy the lattice, resulting in the solid dissolving.</td>
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<td>Magnesium chloride (solid) consists of a 3–D lattice of Mg^{2+} and Cl^- ions. Although charged particles are present, they are held in position by (strong) ionic bonds, and the solid does not conduct electricity.</td>
<td>Diamond is made of carbon atoms. Each carbon atom is covalently bonded to 4 other C atoms in a tetrahedral arrangement, which forms a covalent network solid. The covalent bonds between the carbon atoms are very strong and require a large amount of energy to break them.</td>
<td>Zinc consists of Zn atoms held together in a 3–D lattice by metallic bonding, in which valence electrons are attracted to the nuclei of neighbouring atoms. Zinc is not soluble in water, as the metallic bonds are too strong to be broken by the attraction to the water molecules.</td>
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<tr>
<td>Lead atoms are held together in a 3–D lattice by metallic bonding, in which valence electrons are attracted to the nuclei of neighbouring atoms. Lead's valence electrons are free to move throughout the structure in both the solid and liquid state</td>
<td>Magnesium oxide is made of positive magnesium ions and negative oxide ions, held together by strong electrostatic attractions in a 3–D lattice structure. As these electrostatic attractions (ionic bonds) are strong, they require a large</td>
<td>Zinc chloride consists of a regular array of zinc and chloride ions held together by ionic bonds in a lattice. $ZnCl_2$ will dissolve in water as water is polar and the partial charges on water are attracted to the oppositely charged ion. (This attraction is</td>
<td>ductility</td>
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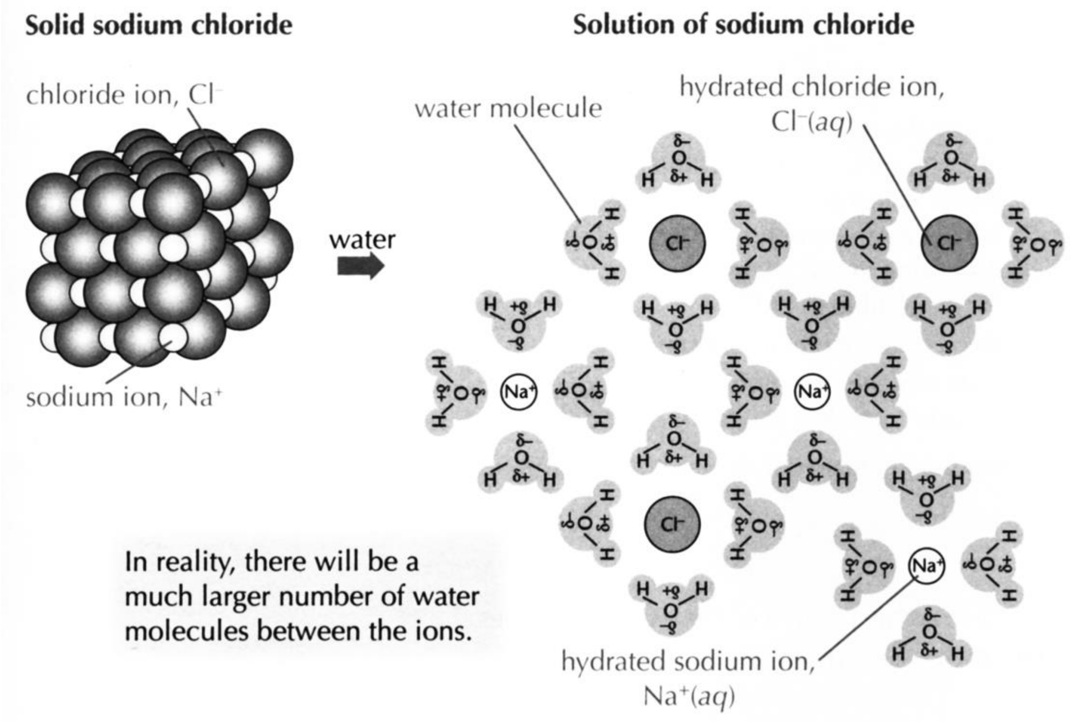
	amount of energy to overcome them.	sufficient to pull the ions from the lattice.)	

Copper chloride (solid) consists of a 3–D lattice of Cu^{2+} and Cl^{-} ions. Although charged particles are present, they are held in position by strong ionic bonds, and the solid does not conduct electricity. When the $CuCl_2$ solid is melted, the ions become free moving, and the free moving ions means the liquid can conduct electricity. When $CuCl_2$ is dissolved in water the ions are then free to move because the ions are no longer held in the lattice. Because of this, the solution can conduct electricity.	**Sulfur dichloride** is a molecular solid, made of molecules. There are weak intermolecular forces holding the molecules together, and they require a small amount of energy to be overcome.	Water molecules are polar, meaning they have a partial negative charge on the oxygen atoms and a partial positive charge on the hydrogen atoms. When **LiCl** is placed in water, the oxygen ends of the water molecules are attracted to the positive Li^{+} ions, and the hydrogen ends of the molecules are attracted to the negative Cl^{-} ions. The water molecules then pull ions from the lattice, resulting in the solid dissolving. Cyclohexane is a non-polar solvent, meaning that the molecule has no charge separation. Therefore, cyclohexane is unable to attract ions from the lattice and the LiCl will not dissolve in the non-polar solvent.	**Copper** is composed of Cu atoms /cations (NOT protons or nuclei) held together in a 3–D lattice by metallic bonding, in which valence electrons are attracted to the nuclei of neighbouring atoms. The attraction of the Cu atoms for the valence electrons is not in any particular direction; therefore Cu atoms can move past one another, and so Cu is ductile and can be drawn out into wires without breaking.
LiCl consists of positive Li^{+} and negative Cl^{-} ions in a lattice, held together by strong electrostatic attractions / strong ionic bonds between oppositely charged ions. When solid, the ions are held in fixed positions in the lattice and cannot move. As there is no free moving charge, LiCl cannot conduct electricity when solid.	**LiCl** consists of positive Li^{+} and negative Cl^{-} ions in a lattice, held together by strong electrostatic attractions / strong ionic bonds between oppositely charged ions. When LiCl melts, the strong electrostatic attractions / ionic bonds between the ions need to be broken so that ions are separated. This requires a lot of energy. Hence, the high melting point of 610°C.	**Potassium chloride** consists of a 3–D lattice of K^{+} and Cl^{-} ions. The ions are held in position by strong ionic bonds. The molecules of a non–polar solvent are not attracted towards the ions and so KCl is insoluble. KCl is soluble in water as the polar water molecules are attracted towards the ions, and the attraction is sufficient to pull the ions from the lattice.	hardness
Sodium chloride consists of a 3–D lattice of Na^{+} and Cl^{-} ions. Although charged particles are present, they are held in position by strong ionic bonds. When the solid is melted the ions become free moving, and the free moving charge means the liquid will conduct electricity	When $\mathbf{S_8}$ melts, the weak intermolecular forces between molecules must be broken. Less energy is required to break these forces.	Iodine molecules are non-polar, therefore iodine is soluble in a non-polar solvent such as cyclohexane. Since both molecules have similar weak intermolecular forces, then weak forces will exist between the two different molecules.	Diamond does not conduct electricity and is hard. Diamond consists of C atoms each covalently bonded to four other C atoms, forming a 3-D tetrahedral arrangement. In diamond, the covalent bonds between the carbon atoms are very strong and hold the atoms in place, making it difficult to break the

			bonds. Therefore diamond is a very hard substance
Copper atoms are held together in a 3-D lattice by metallic bonding, in which valence electrons are attracted to the nuclei of neighbouring atoms. Conduction of electricity requires free moving charges, which are the moving valence electrons.	**Iodine** consists of I_2 molecules and weak intermolecular forces / weak Van der Waals forces exist between the molecules. As these attractions are weak, the molecules are easily separated and the melting point is low.	**Potassium iodide** is an ionic solid consisting of ions held together by strong ionic bonds / electrostatic attractions. Ionic solids are soluble in water as the ions are separated from the lattice due to attraction towards the polar water molecules.	**Graphite** is soft. Graphite consists of C atoms each covalently bonded to three other C atoms in a 2-D or layered arrangement with weak intermolecular forces of attraction between the layers or sheets. However in graphite, although the bonds between the covalently bonded carbon atoms in the layers are strong, the forces between the layers are weak, resulting in the layers sliding over each other. Therefore graphite is a soft substance.
	Potassium iodide is an ionic solid consisting of ions held together by strong ionic bonds / electrostatic attractions. As these attractions are strong, more energy is needed to separate the ions (than the molecules of iodine) so that potassium iodide has a high melting point.		
	Cl_2 consists of Cl_2 molecules. The force existing between the molecules is a weak van der Waals force. As little energy is needed to overcome this weak force the melting point is very low.		
	Graphite or Graphene Graphene has strong covalent bonds. Because the covalent bonds are strong / there are a large number of covalent bonds, it requires a lot of energy to break these bonds, and therefore the melting point is high.		

1) Solubility

When sodium chloride is dissolved in water the attractions between the polar water molecules and between the ions in the salt are replaced by attractions between the water molecules and the ions. The negative charges on the oxygen ends of the water molecules are attracted to the positive Na^+ ions, and the positive hydrogen ends of the water molecules are attracted to the negative Cl^- ions.



Suzanne Boniface, *ESA Study Guide Level 2 Chemistry*, page 115 (Auckland: ESA Publications (NZ) Ltd, 2012), p 115.

2) Silicon dioxide is a covalent network solid. It is made up of silicon and oxygen atoms, with only strong covalent bonds between them. Because the covalent bonds are strong/there are a large number of covalent bonds, it requires a lot of energy to break these bonds and therefore the melting point is high.

3) H_2O – weak force of attraction circled (*force between adjacent molecules*). NaCl – ionic bond circled (*force between positive and negative ions*). Sodium and chloride ions are held together by strong ionic bonds. A large amount of energy is required to overcome these forces. Hence NaCl has a high melting point. The forces of attraction between neighbouring water molecules in ice are weak. Only a small amount of energy is required to separate the water molecules from each other, hence ice has a low melting point. When sodium chloride dissolves in water the ionic lattice breaks up. Water molecules are polar. The positive hydrogen ends of the water molecules are attracted to the negative ions (Cl–) in the lattice, and the negative oxygen ends of the water molecules are attracted to the positive ions (Na^+). The attraction of the polar water molecules for the ions is sufficient to overcome the attractive forces

between the Na^+ and Cl^- ions, allowing them to be removed from the lattice. Hence the sodium chloride solid dissolves, forming separate Na^+ and Cl^- (ions) in aqueous solution.

4) The particles in methane are **molecules**. The particles are held together by weak **intermolecular forces / bonds**. It takes very little energy to break these forces. This results in the low melting point. The particles in calcium carbide are **ions**. They are held together in a lattice by strong **ionic bonds**. These bonds require a lot of energy / are harder to break. This results in the high melting point. The different melting points of these two carbon-containing substances occur because of their different forms of bonding